

Virtual reconstruction of the 400 toneladas nao from Diego García de Palacio's *Instrucción náutica* (1587)

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Abstract

The period between 1570-1620 has left a remarkable amount of documents related to shipbuilding in the Iberian Peninsula. Among them, the *Instrucción náutica* written by Diego García de Palacio in 1587 is widely recognized as the first published book that includes an extensive discussion of ship design and construction. García de Palacio centres his discussion on a 400 toneladas nao, a series of woodcuts that illustrate the shape and dimensions of the ship accompany the explanation. In the late XVI century ship hulls were designed following procedures based upon an old shipwright tradition born in the Mediterranean. By simple rules the master shipwright plots the central frame and tail frames and complete the hull body using wooden ribbands.

Computer software for 3D modelling using NURBS surfaces helps to recreate ships hulls. In this work the 400 toneladas nao is reconstructed and her hydrostatic parameters are compared with other ships.

Keywords: Shipbuilding history, naval archaeology, Hydrostatics, 3D modelling

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1. Introduction

1570-1620 is a rich period in highly technical shipbuilding and navigation documents from the Iberian Peninsula. A number of

manuscripts and books that, either exclusively or as part of a broader maritime theme, furnish key aspects of shipbuilding in those years are known. The early seventeenth century brought the standardization of shipbuilding in Spain through Boards of Builders (*Juntas*). They wrote what became shipbuilding Royal Ordinances enacted in the years 1607, 1613 and 1618, therefore completing the series of highly technical documents of the period.

The Instrucción náutica stands out as the first printed book of this nature. In its pages, the author, Diego García de Palacio, described in detail the proportions of a 400 toneladas ship, a size that he considered to be ideal for both warfare and trade, illustrated with the first printed "design drawings" of a ship.

The emergence of digital tools has eased the tedious task of fairing hull lines. From last century 80s, computer graphics software began to proliferate. Over the years, this tools became widespread in certain areas especially in sailing boats design.

This paper proposes, interpreting García de Palacio's text and applies surface generation software to reconstruct the 400 tons ship's hull to evaluate its hydrostatic properties and compare them with other similar ships.

2. Hull design in late XVI century

Ship design from the late sixteenth and early seventeenth century in the Iberian Peninsula was the result of a refined tradition over centuries of experience that scholars call "Mediterranean" as opposed to the "Atlantic" northern tradition in Europe. The first is associated with the "skeleton-first" system, previously designing some sections on which the hull strakes were properly caulked, while in the "shell-first" system the hull strakes was the first element to be clinker mounted and subsequently frames were nailed.

Since design drawings were not still in use, ship design was based on simple rules and shapes drawn using circular arcs. Most contemporary shipbuilders were illiterate and hardly knew the most basic geometric rules. The procedures were empirical and based on the experience jealously guarded by professional guilds.

However, there were scientists, sailors, builders, owners and even governors of the lands overseas who recorded certain rules and proportions that would ensure the achievement of reliable and resistant ships. One of them is Diego García de Palacio to whom this work is dedicated.

Beginning with the cargo capacity of the ship and based on one constructive measure, which could well be the breadth, in the case of Tomé Cano¹, or the keel length in Fernando Oliveira², main dimensions of the ship were determined by simple geometric rules.

¹ Cano, 1611, p. 14v

² Oliveira, 1570-1580, fol. 69

Until almost the end of the sixteenth century the rule *As, Dos, Tres* (Ace, Two, Three) established during the previous century for the ratios of the breadth, keel, and length measured on main deck and, remains in effect.

To draw the midship section³, the floor (*plan*) is determined as a proportion of the breadth (*manga*) and depth⁴ (*puntal*). As time went, regulators and shipbuilders were adding more parameters thus increasing control over the design, a process that ends with 1618 Royal Regulation (*Ordenanza*) in which over 200 vessel's measurements are standardized. An arc usually made the layout of the midship section to the main deck. They also predetermined the main deck length to give the rakes at bow and stern. A straight line drew the sternpost while an arc is used for the stem.

Two additional cross sections are designed and positioned fore and aft of the midship to generate a "controlled" hull shape. By means of moulds modifying the master frame gauge in the width and rising of the floor, these tail frames, called *almogamas* or *redeles*⁵ were drawn. Later, a third gauge called *joba*⁶ to increase the upper breath at the futtocks and thus preventing the hull to close as the gauge of the floor moves toward the bow or stern, was added. The keel length among the tail frames was filled with the quarter frames or *cuadernas de cuenta*. Geometric instruments determined the narrowing and rising of their floor, so that oval shapes are guaranteed.⁷

The remaining frames in the bow and stern quarters were projected empirically according to the carpenter's guise, using ribbands⁸. This system produced vessels in unpredictable ways that were difficult to reproduce from one ship to another.

3. García de Palacio and the *Instrucción náutica*.

Diego Garcia de Palacio, son of Pero Garcia de Palacio and Maria Sanz de Arce, was born in Ambrosero (Cantabria), in 1542, studied at Salamanca and Valladolid where he graduated in Law. Although some scholars claim that was brought to naval service, there is no evidence of that. He was the oldest of five children, three of whom died in combat.

In 1572 he was appointed "oidor" (equivalent to judge at present) which granted him the privilege of sending correspondence directly to King Philip II.. After arriving in Mexico City, he was appointed University principal in 1581. In 1583 published his first book *Diálogos militares*, which reflected the military tactics developed in Italy with little reference to the New World, so it is assumed that Palacio acquired them from various sources other than his own experience.

In 1589 the Council of the Indies for corruption and abuse of power condemned Palacio, which was common among the "oidores" of the New World. He was suspended for nine years but could not resume his duties since he died in Mexico in 1595.

His *Instrucción náutica* was published in 1587 in Mexico as a small quarto in roman typeface. The 24 drawings included in the text are made by woodcuts and distorted as a result of the printing process. It is written, like his *Diálogos militares* in dialogue format between a *vizcaíno* (a man from Biscay) and a *montañés* (a native of Santander) in imitation of the classical writers, which gives the text a clear instructive form.

The first three books are a compendium of navigation and astronomy. The fourth book is the most original and therefore has attracted the attention of scholars. It includes discussions on the proportions of the ships, masts, rigging, crew responsibilities and naval tactics. The book concludes with a vocabulary of terms *that use people at sea*. It appears to be the earliest published nautical glossary, defining more than 500 terms related to navigation, ship construction, rigging, personnel, and equipment. The inclusion of this lexicon reinforces the inference that the *Instrucción náutica* was intended for a non-specialist audience⁹.

4. Shipbuilding on the *Instrucción náutica*.

The fourth book, entitled "De la quenta y lo que pertenesce a la rosa¹⁰ de qualquier nao" divided into 35 chapters of which the first one addresses the proportions and measurements of ships, on which we will base our study.

After a first half in which he introduces the theme by establishing similarities between human and ship bodies, Palacio determines the units of measure in Castilian cubits (*codos castellanos*¹¹) equivalent to 2 feet (*pies*) or 32 fingers (*dedos*). Felipe II amended those units in 1590 by a cubit of 33 fingers. This new measurement called "*codo real*" or "*codo de ribera*"¹² was widespread used in Spanish shipbuilding.

Palacio determines the most convenient size for a *nao* by her tonnes of burthen (400 *toneladas*) and also gives a definition for *tonelada* by stating "*que dos pipas*"¹³ *hacen una*"¹⁴.

The description begins by giving the main dimensions of the 400 tons *nao*: 34 cubits for the keel length, 16 cubits for the breadth (almost half of the keel) and 11 ½ cubits for the depth (one third of the keel).

We find a definition for depth in the glossary at the end of the book: "Depth of the ship, is the distance that has the ship from keel to main deck"¹⁵

³ The maximum breadth station.

⁴ Depth was taken from the floor timber to the main deck.

⁵ "Almogamas" was the Portuguese Word for the Spanish "redeles", although some Spanish writers like Tomé Cano also took "almogama".

⁶ Tomé Cano was the first writer to mention "joba" although he gives a ver confusing definition on his book.

⁷ Tomé Cano described on his book the method used by Juan de Veas.

⁸ (Loewen, The structures of Atlantic shipbuilding in the 16th century. An archaeological perspective., 1998, p. 244)

⁹ Laanela, 2008

¹⁰ The term is wrong should be screw "rosca" (Fernández Duro, 1880, pág 44)

¹¹ One Castilian cubit was equivalent to 557,23 mm.

¹² One "codo real" was equivalent to 574,68 mm.

¹³ One pipa of wine was equivalent to 430 litres.

¹⁴ (García de Palacio, 1587, p. 92r)

¹⁵ (García de Palacio, 1587, p 152r)

This depth measured to the main deck, was not used in any of the tonnage formulas in force in 1578 but reflected the cargo capacity of the ship. When giving the deck's height there is a correspondence to the *pipa* height mentioned above, and therefore, three tiers of pipes (4,5 cubits) were accommodated in the hold, two on the first deck (3 cubits) and another two on the second (3 more cubits). Adding one cubit for beams, reaches 11.5 cubits as stated in the beginning of the text.

We get data for the reconstruction of the ship: keel (34 cubits), breadth (16 cubits) and depth from the top of the keel to main deck (second) $11 \frac{1}{2}$ elbows, followed by the rakes of the stern ($5 \frac{2}{3}$ cubits) and stem posts (double than the sternpost = $11 \frac{1}{3}$ cubits).

Length on the deck, keel and breadth determine the basic parameters of the proportions of the *As, Dos, Tres* rule, according to which each cubit on breadth gives two for the keel and three for the length on deck. While the rule was not rigorously fulfilled in the text (the actual measures $51 \frac{1}{3}$ - 34-16 give a proportion scheme of 3.2-2.125 -1).

Palacio follows by giving the rising of the floor abaft at $6 \frac{2}{3}$ cubits measured on the sternpost and 12 cubits more giving $18 \frac{2}{3}$ cubits for the sternpost and stem height.

The midship frame¹⁶ is placed two cubits afore the centre of the keel and has to be drawn by a circle arc giving $5 \frac{1}{3}$ cubits for the floor which corresponds to one third of the breadth.

The first question that arises is the height at which the breadth is located, since the author did not give any clue. Eric Rieth¹⁷ worked on a wooden model of the 400 tons *nao* with uncertain fortune. In his work sets the maximum height of the breadth at the first deck following G. de Palacio drawing:

*«le texte ne précise pas de quelle largeur il s'agit. La figure de la coupe transversale de la maîtresse-section permet de constater que la largeur (manga) considérée par Palacio se situe au niveau du second pont»*¹⁸

Jose L. Rubio Serrano¹⁹ on his reconstruction of Palacio's *nao* deemed, in the same way, the maximum beam at $7 \frac{1}{2}$ cubits from the keel although he draws the first deck one cubit above.

We will take the maximum breadth at $7 \frac{1}{2}$ cubits height, same as the first deck. Since midship floor (*plan*) is $5 \frac{1}{3}$ cubits wide, the centre of the circle that describes the first futtock is almost located on the midship axis.

Palacio does not give directions on the frame shape above the first deck. If we follow the drawing on page 94r, we should draw an outer radius curve in such a way that the upper deck beam was almost equal to the maximum breadth and somewhat higher in the rail. Rubio Serrano draws a straight

line from the first deck to the main deck, reducing the beam, which is then extended by a vertical line without measuring the breadth²⁰. Rieth draws an almost vertical line from the first deck level although the trace from the floor do not follow a circle as per Palacio's text.

We will draw a 32 cubits circle arc from the point of maximum beam on the first deck to another point 15 cubits of beam on the top deck giving continuity to the joint. In any case the shape of the ship above the first deck is purely speculative and any proposal is equally valid.

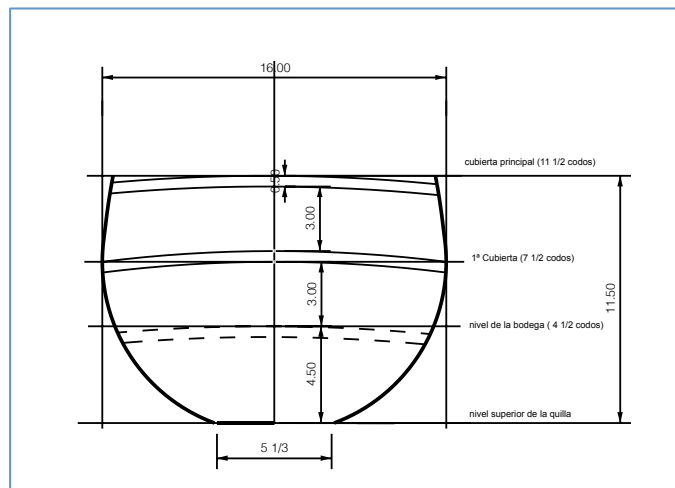


Illustration 1. Midship section reconstruction.
Measures in Castillian cubits. Drawing by author.

The fore tail frame position is determined by the rising of the floor at 9 *maderos* (frames) afore the first tail frame²¹. The rising at this frame is 1,5 cubits.

To estimate the position of this frame we must know the sided scantling of the central frames. One feasible hypothesis is to give $\frac{1}{2}$ cubit (27,8 cm) for the sided of the frames and therefore the sided dimension for a *madero*, which is the floor-futtock assembly, shall be one cubit sided. Bearing this in mind, the phrase "nine timber afore" means that the tail frame was positioned nine cubits afore the midship frame. The dimension is coherent with actual ships reconstructed (Red Bay)²² and E. Rieth²³ makes the same hypothesis based on not specified "written sources".

Palacio gives the aft tail frame position "6 *maderos* abaft the first"²⁴ But some paragraphs after, he gives another statement for the same, "20 *maderos* from the first at the keel centre"²⁵ He also states the rising at 2,5 cubits and 14 cubits for its beam.

¹⁶ Called "*primer madero de cuenta*" (first tail frame) on the text.

¹⁷ (Rieth, *Essai de restitution d'un bâtiment de 400 toneladas*, d'après Diego García de Palacio (1587), 1988)

¹⁸ "The text does not indicate to which beam he is referring to. The illustration of the midship section allows to state that the beam considered (*manga*) is placed at the seconde deck level" (Rieth, *Essai de restitution d'un bâtiment de 400 toneladas*, d'après Diego García de Palacio (1587), 1988, pág 467)

¹⁹ (Rubio Serrano, 1991, vol 1, p. 144)

²⁰ The breadth is 15 cubits, measured from J.L. Rubio's drawing.

²¹ The first tail frame was the midship frame.

²² The sided dimension of the floor timbers in the Red Bay wreck a basque whaler 22 m length built in 1565 is constant at 19 cm.

(Loewen, *The structures of Atlantic shipbuilding in the 16th century. An archaeological perspective.*, 1998).

²³ (Rieth, *Essai de restitution d'un bâtiment de 400 toneladas*, d'après Diego García de Palacio (1587), 1988)

²⁴ (García de Palacio, 1587, p.92r)

²⁵ (García de Palacio, 1587, p. 92v)

The question of the correlation between the tail frames and the rising of the floor is raised at this moment. Some scholars understand that the tail frames would be coincident with the end of the rising of the floor fore and aft²⁶. But those of the XVI century Portuguese shipbuilding as Pimentel Barata²⁷ interpret that at the end of the century a simplification of the technique of calculating the pre-designed frames was put in place reducing their number (Lavanha²⁸ in 1608 prescribes only 10 of them, Oliveira's²⁹ *nao* in 1570 shows 36). This reduction implied that the rising of the floor did not end at the tail frames so we could say that tail frames were the last pre-designed frames of the floor.

For Palacio's *nao*, the text indicates that floor at the stern begins before the tail frame (6 *maderos* abaft the first) that is 20 *maderos* aft. But at the bow Palacio specifies only the beginning of the rising floor (9 *maderos* before the first) and gives the rising at the same position. It is understood that in this case the tail frame is located where the floor begins. However the midship section is placed 17 cubits from the aft end of the keel (2 cubits afore the middle of the keel) and therefore the tail frame will fall outside the keel, which is not possible.

As a first approximation we take the aft tail frame 20 *maderos* abaft the fore tail frame so that the distance between the two is 20 cubits. According to this hypothesis the central body of the ship is filled with 21 *maderos* (11 floors and 10 futtocks)³⁰

The text only gives the breadth at the aft tail frame in 14 cubits. However if we look at page 94r drawings, this measurement should correspond to the fore tail frame leaving about 12 cubits for the aft tail frame breadth.

This fact confirms the inaccuracy of the drawings in the book being engraved on a wooden board for printing and hit by the back, which resulted in serious deformations. E. Rieth³¹ studied the differences in the measures taken on the drawings obtaining an average variation of 6% on the unit of measure (cubit).

Palacio mentions neither procedure to calculate the narrowing nor the rising at tail frames, nor any reference to *joba* or other similar procedure. We can estimate the tail frames floor by measuring the illustrations on page 94r. Bearing in mind their inaccuracy, we guess the fore tail frame floor at 4 cubits and 3 cubits aft, giving the following drawings:

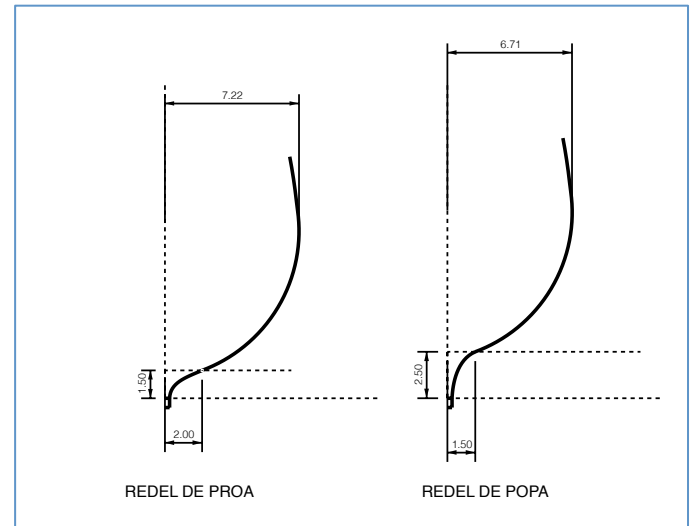


Illustration 2. Tail frames reconstruction. Measures in Castilian cubits. Drawing by author.

It remains to know what is in the breadth at the transom and its shape. Following the text, Palacio described the "dragante" to be $7 \frac{2}{3}$ cubits on breadth. The word "dragante" could be referred to a cross timber to support the bowsprit at the bow. However, it comes from the Italian "tragante" which was the transom on the galleys³². For these reasons, and also because the length of the "dragante", close to half the maximum beam, is consistent with the transom possible measures, we will consider it as such.

We can now draw the transom with a good approximation. We can also draw the fashion pieces with the same radius of the gauge of the master frame (8 cubits) since the author gives no indication of them and assuming the shipwright should use the same mould for all frames on the hull³³.

5. 400 toneladas nao reconstruction

From the data elicited from text and figures we draw the ship profile and sections to support three longitudinal lines: one at the upper deck level, another at the turn of the floor and an intermediate at the head of the first futtock. These lines follow the position where shipbuilders placed the ribbands to trace the fore and aft ends of the hull.

The uncertainty of the hull shape at the quarter ends forces us to be imaginative when drawing those lines. We know from contemporary illustrations that larger vessels had a generous volume at the fore quarter³⁴, and therefore the lines must enter the stem almost perpendicular to the centreline giving "powerful" sections in this part of the hull.

²⁶ Rubio Serrano, 1991, pág. 117

²⁷ Pimentel Barata J. , 1989, vol I, pág. 191

²⁸ (Lavanha, 1608)

²⁹ (Oliveira, 1570-1580)

³⁰ Rubio Serrano gives 13 frames and 12 futtocks. (Rubio Serrano, 1991, vol I, Pág. 122)

³¹ Rieth, Essai de restitution d'un bâtiment de 400 toneladas, d'après Diego García de Palacio (1587), 1988, pág. 473

³² See Contente Domingues, 2004, p. 310 and Hormaechea, Rivera, & Derqui, Los galeones españoles del siglo XVII, p. 295.

³³ It was in 1618 when the Ordenanza prescribed the use of the same mould for all futtocks from stem to sternpost, except for the closing of the stem.

³⁴ Garrote in 1691 still claimed for more volume at the stem to sustain the hull when pitching (Hormaechea, Rivera, & Derqui, 2012, vol 2, P-178).

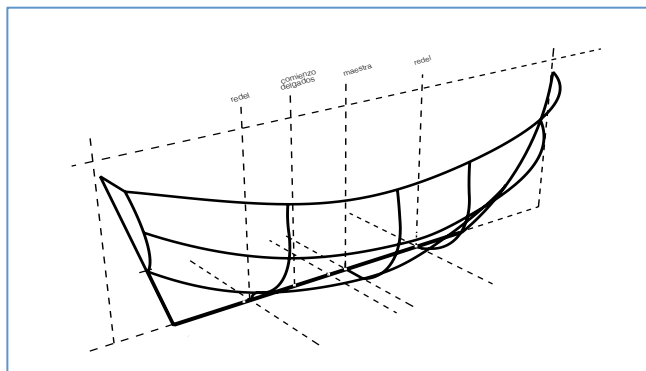


Illustration 3. Principal lines to draw the hull surface. Drawing by author.

We can now draw a surface passing through the longitudinal lines and the five cross sections. The finished hull shape obtained could be seen in the following figure.

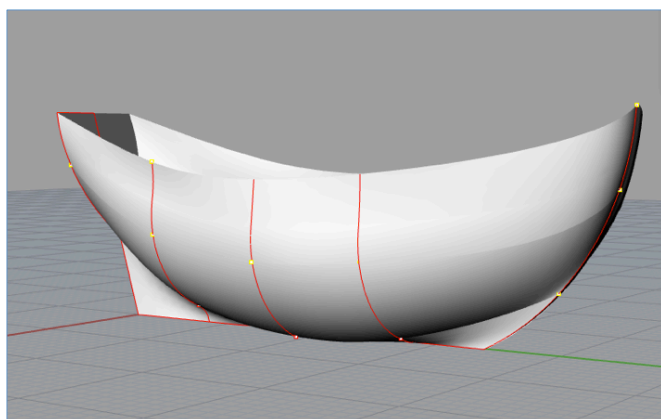


Illustration 4. Reconstruction of Palacio's 400 toneladas nao. 3D view. Master and tail frames in red line. Drawing by author.

6. Hydrostatic analysis.

We convert original units (cubits) into metric³⁵ before transferring the hull surface onto hydrostatic software generating more than 10.000 points-segments grid.

We deem a draught at the maximum breadth at midship, 7 ½ cubits (4,18 m) from the upper face of the keel, half cubit higher than E. Rieth estimation³⁶. Calculations will be done in an untrimmed floatation. Resulting in the lower part of the transom below the waterline. Results are given in the following table:

Center of gravity has been positioned following F. Chapman³⁷ recommendations for barks and cats ships.

³⁵ 1 Castilian cubit = 557,27 mm.

³⁶ E. Rieth estimation was based upon contemporary illustrations depicted on manuscripts where naos appeared untrimmed and transom partially submerged.

³⁷ (Chapman, 1768, p. 135)

MAIN DIMENSIONS		COEFFICIENTS		AREA	
Draught (m)	4,18	Cb	0,496	Wetted surface area (m²)	274,27
Loa (m)	28,23	Cp	0,606	Midship section area (m²)	30,49
Lwl (m)	24,84	Cwp	0,760	STABILITY	-
Bw (m)	8,92	Cm	0,818	GMT (m)	3,59
Bmax (m)	8,92	Immersed Cb	0,491	GML (m)	12,80
TRIM		Immersed Cm	0,810	PARAMETERS	
Fwd Draught (m)	4,18	WATERPLANE		Lw/Bw	2,79
Aft draught (m)	4,18	Waterplane area (m²)	168,36	Lw/f	5,88
Immersed draught (m)	4,22	LCF (m)	11,08	Lw/(Bw*1)	16,38
VOLUME		LCF% [%]	49,73	Bw/f	2,11
Displacement (T)	470,49	TPC (T)	0,00	Cws	2,57
Moulded volume (m³)	459,02	MCT (T-m)	3,10	Cv = volumen de carena/Lw (10³)	29,96
LCB (m)	11,20	BMT (m)	1,75	Superficie mojada/volumen de carena (10³)	4,61
LCB% [%]	50,19	BML (m)	13,80	Circ M (Lwl³)	3,22
VCB (m)	2,55	KMT (m)	4,30	Desplazamiento/Eslora	16,66
TCB (m)	-	KML (m)	16,35	DLR	869,65

Illustration 5. Main hydrostatic characteristics of the reconstruction of 400 ton nao forma Palacio's "Instrucción náutica".

Since hydrostatic analysis is not abundant among marine archaeologists we must rely on different sources from different ages and ship's functions, to frame Palacio's hull shape parameters:

- Urbietta (1450)³⁸. Presumably an oared riverboat.
- J.B. Lavanha³⁹ (1608) 17,5 rumos keel nao and F. Oliveira (1570)⁴⁰ 600 toneladas nao. Both were oceanic vessels for the Indies route.
- Yassida (625), Bozburum (874), Serçe Limani (1025), Culip VI (c. 1300), Contarina I (c. 1300)⁴¹. Mediterranean single masted wrecks from Middle Age except Contarina a two masted lateen ship.
- Hebe frigate (1782), Bellona frigate (1778), Lübeck cog (XV c.).⁴²
- Nossa Senhora dos Martires (1606)⁴³. Portuguese indiaman wreck.
- Victory (1778), Greyhound (1780), Amsterdam (1750) and Batavia (1628)⁴⁴. Ships of the line.

Among them the shipwreck "Nossa Senhora dos Martires"⁴⁵ (1606) is the one that comes closest by its characteristics.

The following table compares Palacio's nao coefficients with other vessels:

³⁸ Rieth, L'epave d'Urbietta une embarcation a clin du millie du XV siecle., 2006.

³⁹ (Lavanha, 1608)

⁴⁰ (Castro, Fonseca, Santos, & Vacas, 2010)

⁴¹ (Fonseca, 2006)

⁴² (Harries, Böndel, Geistert, & Hochkirch, 2000)

⁴³ (Santos, Fonseca, & Castro, Naval Architecture Applied to the Reconstruction of an Early XVII Century Portuguese Nau., 2007)

⁴⁴ (Brown, 1998)

⁴⁵ A reconstruction of a portuguese indiaman based on the analysis of the archaeological remains and archaeological data and the nao presented in Oliveira (1580) for a 18 rumos of keel. (Santos, Fonseca, Castro, & Vacas, 2012)

	García de Palacio	Yassiadá	Bozburum	Serçe Limani	Culip VI	Contarina I	Urbietta	Coca de Lübeck	Oliveira
	1587	625	874	1025	1300	1300	1450	SVX	1570
Draught (m)	4.18	1.77	1.19	1.02	1.44	1.73	0.60	2.78	4.90
Loa (m)	28.23	20.52	14.30	14.55	16.35	20.98	29.60	29.60	28.96
Lwl (m)	24.84	17.20	12.20	12.94	12.81	18.37	10.04	24.56	
Bw (m)	8.92	4.60	4.74	4.64	3.88	5.17	2.55	7.73	12.00
Summerged volume (m³)	459.02	72.45	38.02	38.33	39.80	103.53	6.50	194.00	
Cb	0.50	0.51	0.56	0.62	0.55	0.63	0.42	0.44	0.51
Cp	0.61	0.76	0.62	0.68	0.69	0.76	0.58	0.58	0.67
Cm	0.82	0.68	0.91	0.92	0.80	0.82	0.76	0.77	
Lwl/Bw	2.79	3.74	2.57	2.79	3.30	3.55	3.92	3.18	3.02
Lwl	5.88	9.72	10.25	12.69	8.90	10.62	4.25	8.83	
Lwl*(Bwl)	16.38	36.00	26.00	35.00	29.00	38.00	65.88	28.07	
Bwl	2.11	2.60	3.98	4.55	2.69	2.99	4.25	3.32	2.45

	García de Palacio	Nossa Senhora dos Martires	Lavanha	Batavia	Amsterdam	Bellona	Victory	Greyhound	Hebe
	1587	1606	1608	1628	1750	1778	1778	1780	1782
Draught (m)	4.18	5.00	4.56	4.45	5.17	8.40	4.19	5.63	
Loa (m)	28.23	49.20	39.27	44.01	42.67	45.24	56.69	52.67	52.60
Lwl (m)	24.84	38.10	34.01	44.01	42.67	45.24	56.69	52.67	45.94
Bw (m)	3.92	13.00	10.45	11.49	11.88	15.97	10.12	12.00	
Summerged volume (m³)	459.02	1,298.00	1,192.05	1,170.73	1,178.00	3,404.88	1,132.68	1,350.00	
Cb	0.50	0.52	0.50	0.56	0.54	0.48	0.59	0.51	0.49
Cp	0.61	0.64	0.71	0.75	0.65	0.60	0.65	0.64	
Cm	0.82	0.78	0.82	0.74	0.73	0.81	0.79	0.76	
Lwl/Bw	2.79	2.93	2.72	4.21	3.71	3.94	3.55	5.20	3.90
Lwl	5.88	7.62	9.44	9.99	8.75	8.86	12.55	8.07	
Lwl*(Bwl)	16.38	22.33	39.73	35.61	33.32	31.44	65.18	30.91	
Bwl	2.11	2.60	2.77	2.24	2.58	2.66	2.50	2.41	2.42

Palacio's prismatic coefficient appears to be the lowest (0.576) except for the Lübeck cog (XV c.), which gives us to conclude that the hull proportions of the 400-ton nao was still governed by the previous century *As, Dos, Tres* rule. Comparing with E, Rieth reconstruction ($C_p = 0.621$) the latter is somewhat greater since Rieth placed the tail frames at the end of the keel, which generates fuller forms. Also we must keep in mind that our hull surface has been generated from NURBS while Rieth worked on a wooden block scale model. Palacio's midship section coefficient ($C_m = 0.818$) ranks between 0.75-0.85.

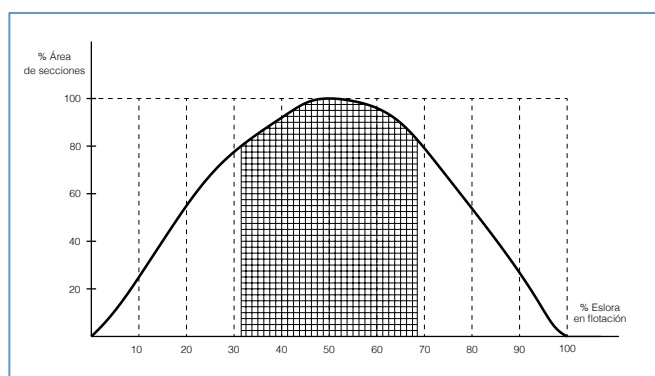
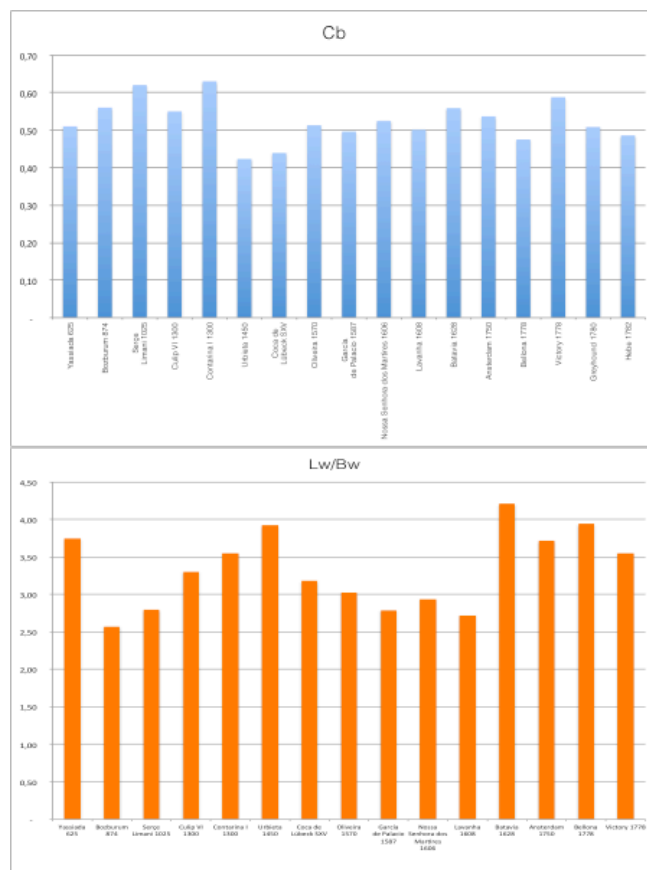


Illustration 6. Area curve showing área between "redes". Reconstruction of Palacio's 400 toneladas nao. Drawing by author.

The area curve shows the centre slightly abaft, keeping the maximum cross sectional area in the middle of the floatation at the midship frame the results are coherent with Palacio's prescription on the midship section placed at 52% from de Loa. The shape obtained is symmetrical and balanced. As time passed the midship section was slightly placed forward searching for more volume to avoid pitching. Thus, Oliveira (1570) placed it at 50,3% abaft the forward end of the length and Lavanha (1611) at 46%. Spanish regulations 1613 and 1618 determined mainframe at 46% abaft the forward end of the length⁴⁶.

⁴⁶ Percentages calculated based on the prescriptions by the author.



Palacio's nao is amongst the lowest Lw/Bw as a result of a tendency towards reducing the length during last XVI and beginning of XVII centuries. We also notice when we take floatation measurements the 3:1 ratio has been lowered by the rake factors higher at XVII century *naos*.

7. Tonnage

Palacio gives the burden at 400 *toneladas*. We should ask if the ship described corresponds to that tonnage, for which the generated model would be of great help.

As discussed in the text, the *toneladas* used to measure the ship cargo capacity are those equivalent to two *pipas de vino*. One *pipa* of 27.5 *arrobas*⁴⁷ was 2,5 cubits height and 1,5 cubits wide⁴⁸. The Andalusia *tonelada* of cargo amounted 8 cubic cubits, that is, 1.38446 m³, which, in turn, was equivalent to two pipes of wine as stated in Palacio's text.

Drawing a 3D model of the *pipa*, tracing the profile via a b-spline curve by successive approximations, we arrive at a base diameter of 1.32 cubits, 1.5 cubits diameter wide and 2.5 cubits height to give a 4 cubic cubits (half-ton cargo) volume solid.

Until the entry into force of the admeasurement⁴⁹ regulations, the burden capacity of a ship was physically measured by checking the number of *pipas* that fit on decks and hold. This work was carried out by the *arruinadores*⁵⁰ of the Casa de

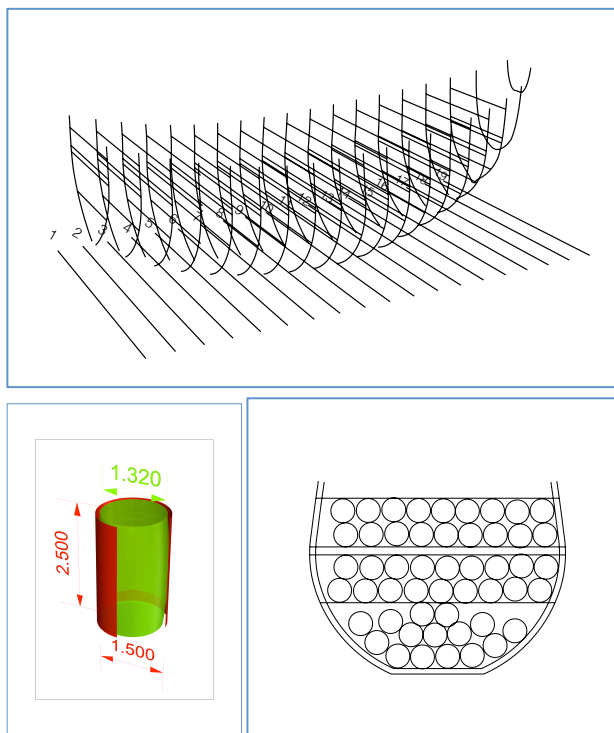
⁴⁷ Arroba was a weight measurement equivalent to 11,5 kg.

⁴⁸ (Casado Soto, 1988, p. 86)

⁴⁹ The spanish Word "arqueo" could come from the word "arco" (arc), the instrument used to simulate the round of the cask.

⁵⁰ "Arruinadores" means literally "bankrupters".

Contratación de las Indias, who were responsible to prevent fraud.



The hull model previously generated could help us in verifying the approximate *pipas* of burden of Palacio's *nao*. After incorporating hold and decks to the model, we draw hull sections every 2,5 cubits (equivalent to a *pipa* length). Counting the number of pipas we obtain the total burden capacity as per the following tables.

	Hold	1st deck	2nd deck	Total
Volume below (m³)	205	263	377	845
Area (m²)	134	175	185	494
Number of pipas	165	243	285	693
pipas/m³	0,80	0,92	0,76	0,82
pipas/m²	1,23	1,39	1,54	1,40

CAPACITY PIPAS				
Section	Hold (vaos vacíos)	1st deck	2nd deck	Total
1		7	7	7
2	3	11	14	14
3	9	13	22	22
4	3	11	14	28
5	7	15	16	38
6	11	16	17	44
7	12	19	18	49
8	15	18	19	52
9	19	19	19	57
10	19	20	20	59
11	21	20	20	61
12	19	19	18	56
13	16	18	18	52
14	11	16	16	43
15	8	14	18	40
16	3	13	14	30
17	1	9	12	22
18		4	10	14
19			5	5
TOTAL	165	243	285	693

Bearing in mind that one *tonelada* was equivalent to two *pipas* we arrive at 346 toneladas burden. This figure maximizes the actual capacity and reproduces how the volume was measured from “arcs” as it was not possible to stow casks so close to each other.

The admeasurement formula in force by 1587 and proposed by Cristobal de Barros can be expressed as⁵¹:

$$\text{Tonnage (toneles)} = \frac{E \times \frac{M}{2} \times P - 5\%}{8}$$

Where: E = Length (*esloría*), M = Breadth (*manga*), P = depth (*puntal*)

All measurements shall be in cubits and taken at the level of the main deck, 5% corresponds to rising of the floors, rigging, beams and pumps⁵² and the divider “8” transform the cubic cubits into *toneladas*.

If we put Palacio's *nao* into the formula, i.e. E = 51 1/3 cubits, M = 16 cubits and P = 7 1/2 cubits we arrive at 365 toneladas, which is close to the figure obtained by drawing the pipas on each deck⁵³. However, the formula takes into account a depth of 7,5 cubits (height from keel to main deck) and we have filled until the upper deck level (11 cubits) following Palacio's text. We can conclude that somehow the formula compensated for all the inner volume when calculating the burden capacity of a ship. The interior volume of the ship as reconstructed is given on the above table to be 845 m³, which give as a ratio of 365/845 = 0,432 toneladas/m³. This ratio is comparable to that obtained from the same formula by F. Castro for the reconstruction of Nossa Senhora dos Martires⁵⁴ at 0,425.

8. Conclusions

The 400 tons *nao* from *Instrucción náutica* is a clear example of the late sixteenth century ships in which the proportions of the rule *As, Dos, Tres* remained. The lack of accurate data when drawing the sections, floor narrowing and rising parameters make reconstruction not only an exercise in understanding the text, but calls for a deep knowledge of the shipbuilding techniques in the late sixteenth century.

NURBs designing tools make possible to elucidate the hull shape depicted in Palacio's book, not without certain licenses when drawing the bow and stern ends. Virtual model enables us to carry out a comparative study with later and preceding ships evaluating the influence of the shipbuilding parameters on hydrostatic coefficients and evaluate admeasurement formulas at that time.

This work procedure could be generalised to other ships and bring to light other contemporary ship hulls. Comparing hydrostatic parameters in the light of the directions given on treatises, would explain certain changes that took place during

⁵¹ Casado Soto, 1988, p. 78

⁵² Cano, 1611, p. 40r

⁵³ C. Rahn Phillips consider depth to be at 7,75 cubits and did not reduced 5% arriving at 397,81 toneladas. She only gives 5% deduction when admeasurement warships tonnage (Rahn Phillips, 1987)

⁵⁴ Castro F. , 2013, p. 1142, table 4, formula (7)

the beginning of the XVII Century enabling the oceanic expansion at the Iberian Peninsula that will be the main subject of my forthcoming PhD thesis.

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